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Understanding Blockchain Technology for Future Supply Chains: A Systematic Literature Review and Research Agenda

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Understanding Blockchain Technology for Future Supply Chains: A Systematic Literature Review and Research Agenda

Abstract

Purpose: This paper investigates the way in which blockchain technology is likely to influence future supply chain practices and policies.

Design/methodology/approach: A systematic review of both academic and practitioner literature was conducted. Multiple accounts of blockchain adoption within industry were also consulted to gain further insight.

Findings: While blockchain technologies remain in their infancy, they are gaining momentum within supply chains, trust being the predominant factor driving their adoption. The value of such technologies for supply chain management lies in four areas: extended visibility and traceability, supply chain digitalisation and disintermediation, improved data security and smart contracts. Several challenges and gaps in understanding and opportunities for further research are identified by our research. How a blockchain enabled supply chain should be configured has also been explored from a design perspective.

Research limitations/implications: Our systematic review focuses on the diffusion of blockchain technology within supply chains and great care was taken in selecting search terms. However, we acknowledge that our choice of terms may have excluded certain blockchain articles from this review.

Practical implications: This paper offers valuable insight for supply-chain practitioners into how blockchain technology has the potential to disrupt existing supply chain provisions as well as a number of challenges to its successful diffusion.

Originality/value: Ours is one of the first studies to examine the current state of blockchain diffusion within supply chains. It lays a firm foundation for future research.

Keywords: blockchain, distributed ledger technology, supply chain management, peer-to-peer communication, systematic literature review

1 Introduction

Considered as one of the most disruptive technologies, the blockchain (a peer-to-peer distributed data infrastructure) enables the creation of decentralized currencies (e.g. Bitcoin), self-executing digital contracts (smart contracts) and intelligent assets that can be controlled over the Internet (smart property) (Kosba *et al.*, 2016; Wright and De Filippi, 2015). Originally created by Nakamoto (2008), recent research on the blockchain has focused primarily on financial transactions and distributed ledger systems (Pilkington, 2016). Blockchain technology uses a shared data infrastructure that updates itself in real-time and can process and settle transactions in minutes using

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3 computer algorithms, with no need for third-party verification. Within the financial sector, the
4 blockchain is proposed as a means for the management of financial transactions without the need for
5 trusted intermediaries such as banks.
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7 However, the blockchain as a technology has potential to disrupt many other domains of
8 organisation, including the supply-chain. Since a blockchain allows secure exchange of data in a
9 distributed manner, it starts to impact upon the way organisations are governed, supply chain
10 relationships are structured, and transactions are conducted. Integrated with other technologies, like
11 the Internet-of-Things (IoT), the blockchain could be used to create a permanent, shareable, actionable
12 record of every moment of a product's trip through its supply chain, creating efficiencies throughout
13 the global economy. Improved visibility facilitated through such technology may also afford product
14 traceability, authenticity, and legitimacy.
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19 Although many speculate about the impact of blockchain technology upon supply chains,
20 current understanding of its potential remains limited. Since the development and diffusion of this
21 technology is still in its infancy, a systematic review of current thinking is likely to assist both
22 academics and managers' sensemaking, where they become aware of this technological innovation,
23 sense its potential disruptive effect, make an initial exploration of its efficacy, and decide whether to
24 either embrace or ignore it. A systematic review will provide a solid foundation by cultivating a deep
25 understanding of blockchain technology when its tangible benefits are unclear, disruptive effect
26 unpredictable and its diffusion path ambiguous. A systematic review will separate the hype from
27 reality by identifying evidence where the blockchain has potential to disrupt supply chains (both
28 positively and negatively), identify challenges to its future diffusion and offer agendas for future
29 research.
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35 Our systematic literature review aims to answer the following question, '***How will the***
36 ***blockchain influence future supply chain practices and policies?***' We further set the following
37 research objectives (ROs) in relation to this research question:
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- 40 • RO1: to identify drivers to blockchain deployment within supply chains;
- 41 • RO2: to identify areas where the blockchain provides the most value for supply chain
42 management;
- 43 • RO3: to investigate the challenges/barriers to further diffusion of the blockchain within
44 the supply chain; and
- 45 • RO4: to develop elements of a future research agenda for the blockchain within the
46 supply-chain.
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51 This paper begins with a high-level description of the architecture of blockchain technology,
52 followed by a discussion of the methodology employed within our investigation. From our research
53 database we identified four major ways in which the blockchain is approached within the extant
54 academic supply chain literature. We further provide a summary of the latest developments in practice.
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3 This is followed by a discussion of the insights the literature provides in terms of our research
4 objectives. We conclude by highlighting our contribution to the literature, as well as considering
5 certain limitations of the research.
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8 **2 Blockchain technology**

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10 Technically, the blockchain refers either to a distributed data infrastructure or a method for
11 recording data using a crypto-analytic hash function. Blockchains consist of nodes situated upon some
12 communication network which utilise some common communication protocol—each node on the
13 network stores a copy of the blockchain and a consensus function is implemented to verify
14 transactions to preserve the immutability of the chain (transactions cannot be changed) (Bashir, 2017).
15 The blockchain can be perceived as another application layer that runs on top of Internet protocols and
16 that enables economic transactions between relevant parties. It can also be used as a registry and
17 inventory system for recording, tracing, monitoring and transacting assets (tangible, intangible or
18 digital). Some think of the blockchain as a giant spreadsheet appropriate for registering all types of
19 assets and an accounting system for transacting such assets on a global scale (Swan, 2015).
20

21 A blockchain is an encoded digital ledger that is stored on multiple computers in a public or
22 private network. Blockchains are comprised of data records, or blocks. As each transaction occurs, it
23 is put into a block. Each block is connected to the one before and after it. Each block is added to the
24 next in an irreversible chain and transactions are blocked together—hence the term ‘blockchain’. Once
25 these blocks are collected in a chain, they cannot be changed or deleted by a single actor. Instead, they
26 are verified and managed using governance protocols (Cheng *et al.*, 2017).
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35 *Figure 1 here*
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37 In a blockchain, no single party controls the data. The entire data infrastructure is visible to all
38 parties. Every party can verify the records of its transaction partners directly, without an intermediary
39 or distributed consensus mechanism. The verification process, along with modern encryption methods,
40 can effectively secure data on blockchain ledgers against unauthorized access or manipulation. Since
41 existing blocks in the chain cannot be overwritten, users always have access to a comprehensive audit
42 trail of activity (Miles, 2017). As such, the bigger the blockchain network, the more tamper-resistant
43 the blockchain will be. The decentralised storage of data reduces the risk of single point of access
44 failure associated with centralised databases.
45

46 Two main types of blockchain are distinguished in terms of access control—who can read a
47 blockchain, submit transactions to it and participate within the consensus process. Within public
48 blockchains, every transaction is public (‘permissionless’) and users can remain anonymous. The
49 network typically has an incentivizing mechanism to encourage participants to join the network.
50 Bitcoin and Ethereum are examples of public blockchains. Within permissioned blockchains,
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3 participants need to obtain an invitation or permission to join. Access is controlled by a consortium of
4 members (consortium blockchain) or by a single organisation (private blockchain).

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6 New applications of the blockchain technology, beyond financial transactions, are being
7 experimented with and exploited in sectors such as financial services, insurance, food, healthcare and
8 government. Within the supply chain, some compelling cases of blockchain adoption have been
9 identified. For example, the blockchain can be deployed as a means of enabling a record of complete
10 provenance details for each component part of an aircraft. These details can be accessed by each
11 manufacturer within the production process (Gupta, 2017).
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15 **3 Methodological approach to literature review**

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18 To help build transdisciplinary understanding of blockchain developments for supply chain
19 transformation we have conducted an integrated and systematic review of both academic and practice
20 literature. A systematic review of academic literature is a well-established method that provides a
21 replicable, transparent and auditable trail of the reviewers' decisions, procedures and conclusions
22 (Bryman, 2012; Tranfield *et al.*, 2003). The systematic review approach can explore the literature in
23 fields that aim to elucidate interventions with specific benefits such as cause and effect analysis
24 (Saunders *et al.*, 2012; Tranfield *et al.*, 2003). The method allows for systematic analyses and
25 syntheses of relevant research by breaking down each study into its constituent parts (Bryman, 2012).
26 This enables a conceptual analysis of the research objects (Tranfield *et al.*, 2003). We follow the
27 structured approach outlined by Tranfield *et al.* (2003) and detailed further by Denyer and Tranfield
28 (2009) and Rousseau *et al.* (2008). It is worth noting that our systematic literature review does not
29 include published books, mainly because some these publications do not usually go through rigorous
30 academic peer reviews. However, we have used certain popular books on the blockchain such as
31 Antonopoulos (2014), Mougayar (2016), Tapscott and Tapscott (2016), Bashir (2017) and Hofmann *et*
32 *al* (2017) to help us understand the ways in which the blockchain is framed in popular literature.
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40 As with many areas of technological innovation, academic studies tend to lag in their
41 application of technologies in practice. Solely relying on journal publications would provide a rather
42 narrow view of the literature. Reviewing the current state of practice is therefore essential to provide a
43 solid ground for understanding how blockchain technology is being used in practice. A wide range of
44 sources was consulted to identify the trend of current industrial exploitation and development of the
45 blockchain.
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49 For instance, public and industrial databases, such as Lloyd's List insights (maritime
50 intelligence), European Commission foresight studies and OECD reports, provide a good indication of
51 current blockchain development efforts at the European and international levels. Industrial forums and
52 trade associations, such as the Chartered Institute for IT, the Chartered Institute of Logistics and
53 Transport, the Global Shippers' Forum and the EU Blockchain Observatory and Forum, were
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1 surveyed on blockchains because these stakeholders tend to be at the forefront of discussions and
2 actions on emerging technological trends. The publications of leading IT service providers and
3 consulting companies, such as IBM, Gartner and McKinsey, were also closely examined, as these
4 represent the latest thinking on blockchain developments. Popular blockchain platforms, such as
5 Hyperledger, R3 Corda, MultiChain and Ethereum, were visited frequently to gather information on
6 the latest developments. Further insights were gained by attending industrial workshops, in which
7 industry leaders discussed their latest efforts in blockchain developments. All these activities led us to
8 identify a list of promising supply chain-related blockchain initiatives, which we discussed in Section
9 5. Information obtained in this way from practice helped in our interpretation and analysis of the
10 academic literature and particularly informed our identification of future research opportunities.
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18 3.1 Pilot review

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21 A pilot systematic literature review was used to decide upon the appropriate breadth for the
22 final literature review. Given that the term *blockchain* was introduced in 2008 (Nakamoto, 2008), our
23 review spans the period 2008 to 2017. Multiple articles discuss the general features of blockchains
24 (e.g. ABI inform global generates 5,667 articles) within this period. To ensure academic rigour and
25 quality, only peer-reviewed scholarly articles were captured (Saunders *et al.*, 2012; Tranfield *et al.*,
26 2003). This method generated a reasonable number of articles to explore, increasing the credibility of
27 selected articles. Other terms such as a *digital ledger*, *distributed ledger* and *shared ledger* were used
28 as synonyms for the blockchain. To be as comprehensive as possible, the keyword string used to
29 collect articles related to blockchain technology was: 'blockchain' OR 'digital ledger' OR 'distributed
30 ledger' OR 'shared ledger'.
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36 As blockchain is an emerging topic in supply chain management, it is necessary that we
37 review research from other fields such as engineering, innovation, IT and finance where the topic is
38 more established. This approach afforded us further insights about the implications of blockchain for
39 supply chain. As pointed out by Holmstrom et al (2009), navigating multiple domains of inquiry is of
40 great value for making theoretical abstractions and abductive reasoning. Abduction of tested results
41 from other field to supply chain management will serve as the basis for explorative design science
42 research. We identified that, due to the rapid development of blockchain technology, a large majority
43 of articles were published in the first half of 2017. However, to ensure the maximum inclusion of
44 relevant publications within our review, an additional search was conducted in December 2017–
45 January 2018, prior to the submission of this paper. Finally, relevant literature discussed in these
46 papers identified, but not captured by our keyword search, was reviewed for a more comprehensive
47 analysis.
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3.2 *Initial selection of articles*

Nine integrated databases that cover heterogeneous disciplines were used to collect the articles: ABI Inform Global, Emerald, IEEE Explore, Jstor, Science Direct, Scopus, Springer, Taylor and Francis and Web of Science. To narrow down the research scope to that of supply chains, only articles including the terms 'logistics', 'supply chain', 'demand chain' and 'value chain' were selected. After this initial review, our search acquired 227 articles.

3.3 *Contents screening and complementary search*

We used a wide definition of supply chain management to include articles related to freight operations, warehousing, integrated logistics, retail/global/cross-border supply chain operations, humanitarian logistics, global trading including shippers and intermediaries. Titles, keywords and abstracts of articles were read to determine their suitability for inclusion. If required, the main texts of the articles were also closely investigated. Articles that clearly specified aspects of the blockchain that support supply chain philosophy or practices received further scrutiny (Bryman, 2012). Moreover, for the identification of supply chain activities or processes supported by the blockchain, articles clearly addressing the purposes of blockchain use were selected (Bryman, 2012). Articles that did not use blockchain technology as their primary focus, such as articles using the blockchain to explain Bitcoins not in the context of supply chain management were excluded. This process retained 24 articles out of 227 articles. Our initial literature review took place between June and December 2017. An additional search using the same method (i.e., initial article selection and contents screening) was conducted between December 2017 and January 2018, which identified five more articles. The total list of 29 selected articles are summarised in Table 1.

Table 1 here

4 Current perspectives and research efforts on blockchains

4.1 *State of art developments in academia*

Although the blockchain is still in its infancy, supply chain researchers have started to recognize its potential for supply chains. Its expected value was discussed in the literature, and actions/implementation strategies required to materialize its value were also proposed. However, the overall state of such research remains generally at the sense-making and exploratory stage.

Blockchain deployments in practices are mostly in the pilot stage, with no evidence of large-scale adoption within the supply chain. Consequently, there is limited empirical evidence as to how the blockchain has benefited or disrupted existing supply chains. We found four major ways in which the blockchain was approached within extant supply chain literature. A small part of this literature

describes pilots that applied the blockchain in agriculture and pharmaceuticals. Some articles addressed the potential of blockchains for the supply chain while others predicted how blockchains will impact supply chains. Finally, certain articles diagnose specific problems with contemporary supply chains and propose the blockchain as a solution to address these issues.

We categorised the studies into four types—descriptive, conceptual, predictive and prescriptive.

- **Descriptive** (3 articles, 10%): Descriptive papers answer the question: *‘How has the blockchain been deployed in the supply chain?’* Piloting schemes in the agri-food and pharmaceutical industries demonstrated the usefulness of blockchain applications in product provenance and traceability.
- **Conceptual** (4 articles, 14%): This stream of literature seeks to answer the question: *‘What does the blockchain mean for the supply chain?’* To provide a better understanding of blockchain technology, conceptual papers interpret its underlying values, disruptive characteristics and consider implications of the blockchain for supply chain management. They also debate whether the blockchain will provide a new paradigm for supply chain management.
- **Predictive** (11 articles, 38%): This stream of literature deals with the question: *‘Where will the blockchain penetrate supply chains?’* It does so by considering possible application areas for the blockchain within the supply chain. The proposed application areas include: cross border digital integration of multiple stakeholders, product traceability, financial settlement, process automation and contract management.
- **Prescriptive** (11 articles, 38%): This stream of literature tackles the question: *‘How should the blockchain be deployed within supply chains?’* Prescriptive papers tend to diagnose current problems within supply chain practices and provide technical and business solutions. They concentrate on the lack of trust in product/information legitimacy caused by information asymmetries within supply chain practices. Various data architectures or conceptual models are proposed to resolve such asymmetries. A limited number of papers report system performance results after trial runs, providing valuable insights into the practicality and cost implications of blockchain deployment.

Although all streams of research contribute to our knowledge of the emerging technology of blockchain, the development of prescriptive knowledge tends to be field problem driven and solution oriented, describing and analysing alternative courses of action in dealing with certain blockchain-related problems. This design-oriented approach enhances the relevance of academic research to practice. If these solutions are ‘well-tested, well-understood and well-documented general solutions’, they can then be used as the basis for the design of a ‘specific variant of it for a specific case’ in practice (van Aken, 2005, p. 23). However, we are not yet at the stage of architecting general

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3 blockchain solutions, as almost all initiatives in practice are still being tested in the piloting stage,
4 which we shall discuss in the following section.
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6 4.2 *State-of-the-art developments in practice*

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9 Many proof-of-concept (POC) or piloting schemes have been developed in recent years,
10 particularly in 2017, using blockchain technology. IBM alone is working with hundreds of enterprises
11 on blockchain implementations (IBM, 2018). Application-specific implementations, such as
12 Everledger for diamond tracking and Filament for IoTs, have emerged. However, concrete, real-life,
13 end-to-end implementations are unavailable as of this writing, providing very limited evidence for us
14 to assess the true impact of blockchain technology on supply chains. Because of the high level of
15 uncertainty associated with current blockchain development, identifying precisely those areas where
16 blockchain technology may hold promise compared with those areas where uptake is unlikely is
17 therefore not possible.
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22 Nevertheless, a review of emerging practices within the supply chain discipline offers us some
23 useful indications on the latest developments. This complements insights gained from our review of
24 the academic literature. Table 2 presents a summary of 17 popular piloting cases we have identified,
25 with the focuses ranging from product provenance and traceability, international shipping and cross-
26 border supply chain to trade finance, secure data exchange and record, smart contracts and social
27 impact. Whilst the main themes evident within this material are largely in line with the academic
28 literature, we do observe a broader range of applications in practice. For instance, blockchain pilots on
29 social impact and trade finance have received less attention in the academic literature but are actively
30 explored in practice.
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36 We summarise some common themes observed from the cases in this section, and then we
37 embed our further discussion of piloting schemes or use cases in Section 5.2, where we explore areas
38 in which the blockchain may provide the most value for supply chain management. In Section 5.4, we
39 showcase some less-known but promising blockchain applications.
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42 An important observation of blockchain initiatives in practice is that most of them deploy
43 permissioned blockchain solutions. Given the sensitivity of supply chain information, this is not
44 surprising, as revealing proprietary details, such as demand, capacities, orders and prices, at all points
45 of the supply chain to unknown participants is unwise. Permissioned blockchains are also more
46 effective at controlling the consistency and integrity of the data that are appended to the blockchain,
47 which is critical for decision making.
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50 Many pilots feature some degree of centralised control. Funding members often form a
51 consortium, which then determines the social structure of the network and how decisions are made.
52 There tends to be a network orchestrator, who is likely one of the funding members, facilitating
53 coordination and cooperation among the different stakeholders in a blockchain-based supply chain
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3 network. This orchestrator plays a critical role in future-oriented value creation, appropriation and
4 distribution among network members. In addition to pursuing socio-economic gains, some consortia
5 have broader aims. For instance, Blockchain in Trucking Alliance is a forum founded in August 2017
6 for the development of blockchain technology standards and education for the freight industry.
7

8 By design, the blockchain enables multiple supply chain stakeholders to transact with one
9 another without requiring an intermediary. Therefore, it seems to be best applied when a problem
10 across multiple parties exists, and these parties can each benefit from addressing the problem. This
11 shared value encourages participation and incentivises collaborative behaviours among participating
12 members. Blockchain technologies also allow competing organisations to become involved in the
13 same network. For instance, IBM Food Trust has multiple retailers on board (see case 1).
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16 Technically, most blockchain projects in supply chains are developed on either Ethereum or
17 Hyperledger Fabric. The former is an open, generic platform (but has recently started to offer private
18 blockchain solutions) that is well known for its ability to execute smart contracts and allow monetary
19 transactions. By contrast, the latter is a private modular platform led by Linux Foundation; it is backed
20 by leading technology service providers, such as IBM, Cisco and SAP, and it aims to advance cross-
21 industry blockchain developments. A major difference between the two is their consensus mechanism.
22 Ethereum relies on mining-based ‘proof of work’ to validate transactions, meaning that all participants
23 need to reach consensus on the order of all transactions that have taken place. It uses a built-in
24 cryptocurrency (‘ether’) to reward miners and pay transaction fees. Hyperledger, in contrast, provides
25 a more fine-grained access control, and only those parties participating in a transaction need to reach
26 consensus.
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35 *Table 2 in here*
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5 Findings and discussion

5.1 RO1: identify drivers to blockchain deployment in supply chains

Trust is the most influential factor driving interest in the blockchain (26 out of 29 articles, 90%) within supply chain management. Trust refers to the reliability of information provided by trade partners, or the safety and security of the data managed by a central authority. Trust is normally discussed as that which perfectly mirrors every dimension of truth regarding events and transactions. Such truth has been described as a 'shared source of truth' (Michelman, 2017, p. 18), 'one data' (Nakasumi, 2017, p. 144) or 'one trusted source of data' (Hull *et al.*, 2017, p. 2). Trust arising from data security was also discussed (Collomb and Sok, 2016; Patel *et al.*, 2017).

Some researchers argue that geographically dispersed facilities and trade partners often lead to disconnections and complexity among supply chain actors. Therefore, acquiring and maintaining reliable data is critical. In this context, the blockchain's role is to provide seamless networks (Bonino and Vergori, 2017; Wang *et al.*, 2017; Xu *et al.*, 2017), entire visibility (Li *et al.*, 2017) and symmetric information to all (Nakasumi, 2017). Such seamless connectivity and reliability are also required for business ethics and social responsibility. Due to the increasing concerns of food safety (e.g., horsemeat scandal in the UK, toxic milk powder in China) (Tian, 2016, 2017) and sustainability related issues (e.g. child labour, fair-trade, organic products) (Abeyratne and Monfared, 2016), consumers pay much more attention to the authenticity and legitimacy of the products they purchase. They increasingly demand to know how, when and where products are sourced and processed.

Another motivational driver to blockchain deployment is public safety and security. To prevent antisocial behaviours, like terrorist attacks on ships and maritime containers, Engelenburg *et al.* (2017) proposed the implementation of blockchain-based customs systems. Mackey and Nayyar (2017) argued that the grey market that commercialized fake products calls for blockchain technology implementation. Corruption and fraud is a serious problem in some developing economies. Guo and Liang (2016) and Kshetri (2017b) posited that the blockchain is required to resolve such legal issues by providing much needed transparency. Table 3 summarises the key drivers for blockchain adoption in supply chains.

Table 3 here

5.2 RO2: identify areas where blockchain provides the most value for supply chain management

5.2.1 Extended visibility and product traceability.

As evident in Table 1 blockchains are expected to add the most value to supply chains through their extended visibility and product traceability. As such, product traceability will likely be the point at which the blockchain sees large-scale deployment. Centralized IT platforms/systems often inefficiently gather and authorize every piece of data along a supply chain. Blockchain-enabled

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3 transactions (a series of transactions required to get a product from place to place) offer transparency
4 to participating companies. A block could be created for each transaction following the product's
5 digital footprint, from manufacturing to distribution and sale (Patel *et al.*, 2017). This level of
6 transparency and visibility is essential for improving the traceability of products and ensuring product
7 authenticity and legitimacy (Casey and Wong, 2017; Lu and Xu, 2017; Mansfield, 2017). Real-time
8 tracking is made possible when the blockchain is integrated with field sensor agents (Li *et al.*, 2017).
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11 Moreover, the use of time-stamping enhances information completeness. Time-stamping is
12 the process of providing a temporal order among sets of events (Abeyratne and Monfared, 2016).
13 When an event is recorded in the chain chronologically, each node (a header in a block) contains a
14 field with a time-stamp recording of the event (Engelenburg *et al.*, 2017). Hence, it can prove the
15 existence of certain data at a point of time. With this logic, time-stamping supports the management of
16 time-sensitive issues by providing a record of historical events (Yuan *et al.*, 2016; Lee and Pilkington
17 2017). Information completeness is also enhanced by the wide range of data that a blockchain system
18 accommodates. Data in a blockchain can include ownership (chronological list of owners), location
19 data (places the material has been and where is it now), product specific data (attributes and
20 performance of the products) and environmental impact data (energy consumption, CO₂ emission, etc.)
21 (Abeyratne and Monfared, 2016). Data could also contain price, quality, date and state of the product
22 (Lee and Pilkington, 2017).
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30 By design, every transaction along a blockchain supply chain is fully auditable. The extended
31 traceability afforded by the blockchain benefits industries that are sensitive to products and material
32 provenance. Some advocate the use of the blockchain to trace the origin and production process of
33 food ingredients (Foerstl *et al.*, 2017; Tian, 2016) and the ownership of luxury textile products
34 (Toyoda *et al.*, 2017). Advocates also propose the blockchain as a solution to manage counterfeit
35 medicine. For example, Mackey and Nayyar (2017) ascertained that a blockchain will enable the
36 tracking of pharmaceutical raw materials and finished goods, making it easier to detect fakes by
37 allowing blockchain participants to verify the authenticity of data. Hence, the blockchain might serve
38 as an open standards technology to integrate various databases and different actors within the
39 pharmaceutical supply chain.
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45 In practice, crucial supply chains, such as food, diamond and pharmaceutical products, have
46 become the hotspots for blockchain initiatives (see cases 1–4 in Table 2). These supply chains carry a
47 sense of urgency for reliable traceability and product provenance. Knowing the origin and the
48 footprints of how products have travelled throughout the supply chain delivers not only commercial
49 benefits, such as improving consumer confidence towards the brand (cases 2 and 3), but also serious
50 safety consequences, such as in the case of aircraft manufacturing (case 4) or food traceability (case 1).
51 Walmart's recent trial has demonstrated that blockchain-enabled tracking takes only 2.2 seconds to
52 trace a package of sliced mangoes from its US stores back to its source Mexico farms, whilst
53 previously, it used to take about 7 days using conventional tracking methods (McKenzie, 2018). This
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3 blockchain based tracking allows food retailers and manufacturers to respond quickly to recalls and
4 other food safety issues, thus reducing the spread of foodborne illnesses.
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6 5.2.2 *Supply chain digitalisation and disintermediation.*

7 Disintermediation implies that the integrity of data in a blockchain is guaranteed by a whole
8 network, not by an intermediary (Michelman, 2017). For financial transactions, it means that peer-to-
9 peer (P2P) asset transfers and interfirm trading/payments occur without the authentication of a third
10 party (Yuan *et al.*, 2016). Michelman (2017) claims that the blockchain reduces verification and
11 transaction costs by removing intermediaries. Wang *et al.* (2017) argue that the P2P network is
12 particularly useful for temporary business relationships as it reduces the cost of building trust. Polim
13 *et al.* (2017) propose a blockchain system that allows retailers to directly tender their shipments to
14 third-party logistics (3PLs), removing fourth-party logistics services (4PLs) from the network.
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19 The attributes of the blockchain are ideally suited to large networks of disparate parties and
20 are seen as a viable solution to ease the complexity of global supply chains (Abeyratne and Monfared,
21 2016; Nakasumi, 2017). International trade is considered the most complicated supply chain practice
22 as it involves large numbers of supply chain stakeholders. Most processes are also paper-based,
23 causing delays, and hindering the efficient flow of goods. Centralized platforms are the main
24 transaction paradigm (Harris *et al.*, 2015), but there are certain limitations when dealing with a large
25 volume of fast-paced transactions (Casey and Wong, 2017). A blockchain-based platform could help
26 digitise paper-based documentation, and establish an immutable, shared record of all transactions
27 among network participants in real-time. Table 4 offers a comparison of current practices and
28 blockchain-enabled international trade and supply chains.
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35 *Table 4 here*

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38 Guo and Liang (2016) report that by replacing trade finance (where banks act as financial
39 mediators) with a blockchain platform, the processing time can be reduced from 7–10 days to 1–4
40 hours. Engelenburg *et al.* (2017) argue that a blockchain would provide real-time visibility of
41 shipments directly to customs authorities, significantly improving the information available for risk
42 analysis, safety and security control (Kshetri, 2017b).
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45 International trade tends to involve a variety of stakeholders and supply chain actors. Its
46 complexity often results in the lack of information visibility—which can be unethically or illegally
47 exploited (Abeyratne and Monfared, 2016; Nakasumi, 2017). Collomb and Sok (2016) argue that the
48 blockchain could address the third world's corruption problem in international trade due to its
49 transparency.
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52 In practice, maritime shipping lines and ports (see cases 5–7 in Table 2) have been actively
53 exploring blockchain-enabled solutions that address the inefficiencies caused by a low level of
54 digitisation within complex cross-border activities. For instance, a simple shipment by Maersk of
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3 refrigerated goods from East Africa to Europe in 2014 was found to have gone through nearly 30
4 people and organisations, including more than 200 different interactions and communications among
5 them (IBM, 2017a). In cross-border trade, the costs associated with trade documentation processing
6 and administration could be up to one-fifth of the actual physical transportation costs (Maersk Press
7 Release, 2018).
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10 In 2016, a blockchain pilot was initiated jointly by IBM and Maersk to improve the workflow
11 and visibility of each shipment. Multiple stakeholders were involved, including trading partners,
12 government authorities and logistics companies. Each participant in this blockchain network can view
13 the progress of cargo through the supply chain and determine where a container in transit is. Each
14 participant can also see the status of customs documents or view bills of lading and other data. The
15 detailed visibility of a container's progress through the supply chain is enhanced with the real-time
16 access to original supply chain events and documents. No one party can modify, delete or even append
17 any record without the consensus of others on the network (IBM, 2017a). Following the successful
18 pilot, IBM and Maersk have announced a joint venture to commercialise the initiative (White, 2018).
19 This endeavour signals the dawn of a wider diffusion of blockchain technology in supply chains,
20 going beyond the POC and pilot stage.
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27 *5.2.3 Improved data security for information sharing.*

28 Thirteen articles (45%) within our review stated that decentralization is a unique data security
29 mechanism of the blockchain. Collomb and Sok (2016) and Tian (2016) point out that a centralized
30 database has three potential deficiencies in that information can be corrupted, falsified, and generated
31 asymmetrically, sometimes causing data to be lost or hard to retrieve.
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34 The data in the blockchain is immutable because the sequence of transactions is saved in
35 chronological blocks of nodes broadcast to all other nodes (Tian, 2016). The stored data is tamper-
36 proof as the updating and deletion of transactions is prohibited according to the consensus mechanism
37 (Patel *et al.*, 2017; Weber *et al.*, 2016). This is an important advancement as any falsification of the
38 information has to be done in real-time, making it much harder than simply substituting new data
39 (Shireesh and Petrovsky, 2016). Patel *et al.*, (2017) argue that the merit of this mechanism is fault-
40 tolerant because multiple sources of original information are available. Ultimately, increased data
41 security would lead to increased confidence and trust of transactions between supply chain partners
42 and end-consumers.
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48 Security in data sharing is important to supply chain actors as business transactions often
49 contain highly-sensitive commercial information. A permissioned blockchain may be of particular
50 value to the supply chain as it offers enhanced privacy, auditability and increased operational
51 efficiency (Gupta, 2017; Weber *et al.*, 2016). With a blockchain supply chain, actors can encrypt the
52 description of goods and sensitive information and use business rules to control access by customs and
53 required bodies (Engelenburg *et al.*, 2017; Kshetri, 2017b).
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3 Blockchain-enabled data integrity and security also protects against fraud and cybercrime.
4 Cybercrime leads to data breaches, financial crimes, market manipulations, theft of IP and poses
5 public safety and security risks. The vulnerability of the supply chain and logistics system was clearly
6 illustrated by the recent case of the NotPetY, a cyberattack to the world's largest container shipping
7 line, Moller-Maersk. The attack affected all its business units' operations, resulting in \$300 million of
8 lost revenue (Milne, 2017). Although there might be various factors contributing to this vulnerability,
9 deploying a decentralised system could mitigate the threat. A key weakness of a centralised system is
10 that if a system is hacked or there is some technical malfunction, the whole system may be brought to
11 a halt. The blockchain offers an alternative way to manage data and is more resilient to such hacks.
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16 Blockchain technology offers highly secure and immutable access to supply chain data.
17 Although this indelibility applies to all blockchain use scenarios, it is of particular value to cases such
18 as those in 12 and 13 in Table 2. In case 12, Google is working with NHS to develop a private
19 blockchain for storing patient data and affording a coordinated approach to the management of health
20 records. In case 13, FedEx piloted a blockchain initiative for data storage after having experienced a
21 high-level cyber-attack. The blockchain has no single point of failure, so it is more resistant to attack.
22 The same information will be available to all participants, so potential conflicts among participants
23 regarding a particular transaction are reduced. Smart contract logic can be written into a blockchain to
24 further reinforce contractual agreements and mitigate potential disputes.
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30 5.2.4 *Smart contracts.*

31 The notion of a smart contract may be the most transformative blockchain application for
32 supply chains. A smart contract is a computerised transaction protocol that automatically executes the
33 terms of a contract upon a blockchain. The general objectives are to satisfy common contractual
34 conditions, while reducing the costs and delays associated with traditional contracts (Gupta, 2017).
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37 Smart contracts are considered of utmost value to supply chain automation and self-execution
38 by 52% of the literature (15 articles). A smart contract can be made partially, fully self-executing, self-
39 enforcing and can be monitored by the network (Weber *et al.*, 2016). For example, a smart contract
40 might send a payment to a supplier as soon as a shipment is received by the buyer. A GPS-tracked
41 product return could log its location in real-time and trigger a signal within the blockchain for
42 immediate refunds. A smart contract, thus, eliminates payment withheld issues and improves
43 efficiency by eliminating contract registration, monitoring and updating efforts and time (Collomb and
44 Sok, 2016; Wang *et al.*, 2017). Bocek *et al.* (2017) claim that smart contracting reduces the number of
45 intermediaries and requires less manual interventions, resulting in reduced operational cost.
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51 Smart contracts could be deployed by sectors where supply chains are temporary and
52 fragmented with multiple tiers of suppliers and subcontractors. Due to the large number of supply
53 chain stakeholders involved in a construction project, it is difficult to track the progress status of
54 agreed tasks and settle financial payment accordingly. Smart contracts can automate processes like
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3 delivering the agreed contracts to specified parties for digital execution, updating programmes based
4 on agreed variations or compensation events and releasing copyright documents to relevant parties
5 (Kinnaird and Geipel, 2017; Wang *et al.*, 2017).
6

7 Smart contracts are mostly being piloted within financial transactions and settlements (see
8 cases 14 and 15) in practice. In the automotive sector, a German start-up, Slock.it (case 14), has
9 piloted the digital wallet blockchain initiative, which automates the payment process when a
10 passenger car is charged at a charging station. Although the pilot is for passenger cars only, when it is
11 extended to commercial vehicles, frictionless machine-to-machine charging will have a significant
12 impact on logistics operations. In pilot case 15, a smart contract is used by Barclays to trigger
13 automatic payment at the point where cargo ownership changes.
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16 A smart contract feature is not available to all blockchains but is becoming desired
17 functionality due to its flexibility and power to include business logic under certain conditions.
18 However, this is also where disruptions are the most severe. Smart contracts imply significant
19 technological (e.g. security), legal (enforcement mechanism when disputes arise) and societal (e.g.
20 removal of intermediaries and potential job losses) implications. The adoption of smart contracts
21 fundamentally changes both organisational and supply chain structures and governance, and hence it
22 may take decades for it to become the norm within supply chain management (Hull *et al.*, 2017; Wang
23 *et al.*, 2017).
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30 5.3 RO3: investigate the challenges/barriers to its further diffusion within the supply chain 31

32 Although the literature agrees that the blockchain will disrupt the status quo and transform
33 supply chain practices generally for the better, this technology clearly presents many challenges.
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37 5.3.1 Organisational and user-related challenges. 38

39 Current economic winners may resist change out of the fear of losing revenue models
40 (Michelman, 2017). For example, banks may be reluctant to coordinate blockchain-enabled business
41 transactions (Zhao *et al.*, 2016). It is reasonable to assume that other intermediaries may have the
42 same fear of being removed from supply chains and resist its deployment.
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45 Other supply chain actors may not want the total transparency provided by a blockchain.
46 Unwillingness to share valued information has long been recognised as a barrier to effective supply
47 chain performance (Fawcett *et al.*, 2007; Kembro *et al.*, 2014). The technical complexity of the
48 blockchain makes it a challenge for individual users to understand, accept and have confidence in
49 participation. Some negative perceptions are associated with blockchains due to the use of Bitcoin for
50 nefarious or criminal purposes (Hoy, 2017; Kshetri, 2017b)
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54 The blockchain affords pseudonymity, meaning that all transactions are transparent, yet are
55 not explicitly connected to real-world individuals or organisations. However, this anonymity could be
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3 broken, connecting individual transactions to parties. This may not be of concern for upstream
4 suppliers. For instance, for individual farmers in the food sector, this transparency brings marketing
5 and branding benefits. However, for downstream consumers, their privacy may be compromised and
6 sensitive detailed personal information revealed (Boucher *et al.*, 2017). There are also environmental
7 concerns regarding blockchains as it requires a high level of energy consumption to maintain the
8 network (Hoy, 2017; Kshetri, 2017b).
9

12 13 5.3.2 Technological challenges.

14 Although the blockchain is perceived as a highly secure decentralised data infrastructure,
15 hacking is still possible. It can happen when a group of miners temporarily control over 50% of the
16 network's mining hash-rate (the measurement unit of processing power of a network of nodes that
17 power a blockchain) (Yuan *et al.*, 2016; Zhao *et al.*, 2016) While hacking into a public
18 (permissionless) blockchains requires significant financial and computational power, a permissioned
19 blockchain may be more prone to cyber-attack (Patel *et al.*, 2017).
20

21 Latency is another barrier, since time passes for each verified block of transactions to be
22 added to the ledger (Wang *et al.*, 2017). For Ethereum, one of the most popular blockchains for smart
23 contracts, this occurs 'approximately every 17 seconds—a far cry from the milliseconds to which we
24 are accustomed while using non-blockchain databases (Ream *et al.*, 2016)'. Effective incentive
25 mechanisms for miners are needed to improve system performance (Nakasumi, 2017). For fast-paced
26 scenarios, private customised blockchains work best (Weber *et al.*, 2016).
27

28 The blockchain protects the system from any type of manipulation by interested parties, but at
29 the same time this may also create problems. When mistakes happen, these cannot be reversed (Patel
30 *et al.*, 2017). Equal and opposite transactions could set records straight. Finally, interoperability
31 between blockchains and integration with existing IT systems need to be addressed to ensure smooth
32 data transfer (Collomb and Sok, 2016; Korpela *et al.*, 2017; Patel *et al.*, 2017; Wang *et al.*, 2017).
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34 35 5.3.3 Operational challenges.

36 For a blockchain to work in the supply chain, all related supply chain actors should be on
37 board (Kshetri, 2018). Blockchain-enabled global supply chains operate in a complex environment
38 that requires various parties to comply with diverse laws, regulations and institutions. Implementing a
39 blockchain in such an environment is an extremely complex task (Casey and Wong, 2017). The
40 blockchain, while tamper-proofing the digital attributes of transactions, could not always accurately
41 mirror the physical movement of materials in the supply chain (Shireesh and Petrovsky, 2016). In
42 reality, accidental errors, conflicts of interests, corruptions and malicious attacks could still happen
43 (Boucher *et al.*, 2017; Kshetri, 2018).
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45 Chen *et al.*, (2017) raised questions as to what data should be stored in blockchains,
46 how such data will be collected and fed into the system and who should be responsible for data input
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3 and provision. The cost of implementing or participating in a blockchain system may also be an issue,
4 due to the technical and specialised expertise required for participation (Patel *et al.*, 2017; Wang *et al.*,
5 2017). It may be even more challenging for small-to-medium-sized supply chain companies to
6 participate, due to their lack of skills and financial constraints.
7

8 Finally, as blockchains place trust and authority in a decentralised network, it represents a
9 total shift away from the traditional ways of organising and managing a supply chain. The loss of
10 control may be unsettling for many supply chain actors. Therefore, cultural resistance and existing
11 business processes will be major barriers to change (Patel *et al.*, 2017; Wang *et al.*, 2017).
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14 5.4 RO4: develop a future research agenda

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18 There is a clear lack of theory and methodological pluralism in much of the literature we
19 reviewed. None of the papers under review deployed an explicit theoretical lens. An alarming majority
20 of papers were either conceptual or technical in nature. Theory is an indispensable part of the research
21 of technological innovations and adoption in supply chains. There is an urgent need for systematic
22 inquiry to study blockchains from a multi- or inter-disciplinary perspective. Rigorously developed
23 conceptual and empirical contributions will improve our understanding of this emerging technological
24 phenomenon and its impact on supply chains, industries and the wider society.
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28 Given the embryonic state of blockchain technology, there are many exciting research
29 opportunities for the future.
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32 5.4.1 Cryptocurrency and supply chain finance.

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35 Studies need to explore how digital currency, or cryptocurrency, may affect supply chain
36 finance. Supply chain finance is a generic term for a variety of financing instruments that finance
37 various parties within a supply chain and support the movement of capital behind a physical supply
38 chain (Pfohl and Gomm, 2009). Given that most established applications of blockchains are
39 cryptocurrency, supply chain partners may start to trade and settle their payments using
40 cryptocurrency. A particularly promising area where we may see cryptocurrency is as a data
41 marketplace for IoTs. With the increasing number of IoT devices in supply chains, they generate
42 tremendous volumes of data, and this data could provide business intelligence about supply chains.
43 Big data is so valuable that it has become a new asset class for supply chain management. Early
44 efforts in practice utilise distributed ledger technology (not necessarily the blockchain) to allow
45 businesses to securely store, sell and access data streams generated by IoTs (see IOTA.org).
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50 Another example is OriginTrail (Cases 11 in Table 2), a Slovenian IT company specializing in
51 traceability and quality-control systems, which created the cryptocurrency, Trace Token. The purpose
52 of this currency is to serve as compensation for multiple nodes within a network that keep copies of
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3 transactional data generated by supply chains (Bowman, 2018). This may address the issue of high
4 transaction costs associated with the blockchain and would speed up cash-flow exchanges.

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6 Smart contract enabled transactions may allow instant payment from customers to suppliers.
7 This shortens the cash payment cycle but does not solve the issue of the upfront need for funds to keep
8 the production/service running by suppliers or buyers. To address this issue, blockchain-based
9 financial service platforms have been piloted in practice. For example, the financial services arm of
10 iPhone manufacturer, Foxconn of Taiwan, partnered with the Chinese online lender, Dianrong, have
11 launched Chained Finance, which claims to be the first-ever blockchain platform for supply chain
12 finance (Case 9 in Table 2). The two companies recently completed a successful pilot and proof of
13 concept by securing funding for small and medium enterprises (SMEs) in China that were otherwise
14 unable to secure needed capital. During the pilot, Chained Finance originated US\$6.5 million
15 (RMB45 million) in loans for these SME supply chain operators (Sawers, 2017). In April 2017, IBM
16 and the Chinese firm, Sichuan Hejia Co., Ltd., announced the launch of a blockchain-based, supply
17 chain financial services platform for pharmaceutical procurement to help improve the efficiency,
18 transparency and operation of supply chain finance (IBM, 2017b). Again, this platform is beneficial to
19 SME companies which often find it difficult to raise funds due to underdeveloped credit systems and a
20 lack of established credit evaluation and risk control. The platform is designed to help establish the
21 authenticity of the transactions among supply chain participants, allowing banks to be more informed
22 and grant access to funding for SME pharmaceutical retailers. The blockchain's ability to track
23 ownership in a distributed and immutable way could also potentially lead to new crowdfunding and
24 peer-to-peer lending initiatives (Collomb and Sok, 2016). Similar cases (Cases 8 and 10) are also
25 observed where financial transactions are carried out using blockchain technology.

26
27 Research in supply chain finance is very limited (Caniato *et al.*, 2016; Carter *et al.*, 2015).
28 Research that bridges blockchain and supply chain finance is nearly non-existent. As such, blockchain
29 diffusion into the supply chain provides fertile ground for future research. Examining this emerging
30 phenomenon would offer valuable insights about how blockchain supports financial collaboration
31 across supply chain echelons, not just bilateral financial settlement. More importantly, it will allow us
32 to interrogate the economic value of the blockchain and see whether it affects the bottom line of the
33 business.

34 35 36 37 38 39 40 41 42 43 44 45 46 5.4.2 *Disintermediation and reintermediation.*

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48 The elimination of intermediaries in the market system, as claimed by blockchain
49 communicators (Tapscott, 2016), will address the asymmetrical issues among economic participants
50 and allow peer-to-peer asset trading. Disintermediation often occurs when a novel technology
51 application could take the cost or time out of the supply chain or add more value to customers (Shunk
52 *et al.*, 2007). For supply chains, the blockchain may cause the extinction of certain types of
53 intermediaries. However, it is hard to fully predict its impact on the structure of markets and supply
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3 chains. Some compare the current level of development to the Internet and World Wide Web in the
4 early 1990s. Just as TCP/IP dramatically lowered the cost of connections, the blockchain could
5 dramatically reduce the cost of transactions (Iansiti and Lakhani, 2017)
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7 When the Internet was first commercialised, it reshuffled many industries by removing some
8 traditional intermediaries, while leading to a plethora of new types of intermediaries. For example, in
9 the book sector, when electronic marketplaces were introduced, the business of the traditional
10 wholesaler/distributor was severely disrupted. However, new intermediaries like Amazon and eBay
11 emerged, generating value by providing value-added services to participants (O'Reilly and Finnegan,
12 2010).
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16 Future research should explore whether supply chains will still need banks to settle financial
17 transactions, whether transport service providers will be eventually phased out from supply chains and
18 whether the echelons such as distributors/wholesales/service agents will still add value in blockchain-
19 enabled supply chains. Disintermediation will take place if the cost of existing supply chain
20 intermediaries exceeds the value they add. Meanwhile, a new breed of intermediaries may emerge,
21 which will seize the missing opportunities in the supply chain and promote greater economic,
22 environmental, and social benefits. Research into these new intermediaries and the effect of
23 reintermediation will provide further insight about the change of supply chain structures generated by
24 blockchains.
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30 *5.4.3 Digital trust and supply chain relationship management.*

31 Blockchains are often recognized as the missing trust layer of the Internet and as such may
32 challenge the conventional ways of understanding and researching 'trust' in supply chains. Trust is a
33 key catalyst to building close supply chain relationships and has a positive impact on innovation and
34 supply chain performance (Kwon and Suh, 2005; Panayides and Lun, 2009). Trust also influences the
35 risks associated with collaborative projects. High levels of trust enhance joint decision-making and
36 problem solving which mitigate many execution problems and increase the probability of success
37 (Fawcett *et al.*, 2012). Research also suggests that interdependence fosters trust between supply chain
38 partners (Capaldo and Giannoccaro, 2015). Nyaga *et al.*, (2010) posited that supply chain
39 collaborative activities lead to trust and commitment, which lead to improved satisfaction and
40 performance.
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46 The research on trust in buyer-supplier relationships has emphasised the need for long-term
47 relationships and mutual investment between supply chain actors to build trust (Fawcett *et al.*, 2012;
48 Handfield and Bechtel, 2002; Kwon and Suh, 2004). With ongoing globalisation and the growing
49 complexity and volume of global transactions, this approach is becoming more time-consuming,
50 costly and inefficient. With the blockchain, 'trusting' supply chain partners may be irrelevant. Given
51 that the trust has been 'programmed' into a blockchain through cryptography, relational investment is
52 not as essential as in traditional supply chains. In a blockchain, people, businesses or things come
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3 together spontaneously to interact in a well-defined context. The 'trust' only extends to the requested
4 action at that point in time, and that may change rapidly as conditions change. A blockchain-enabled
5 supply chain may be established via the orchestration of a variety of services to fulfil a certain demand
6 or order. Once the order is fulfilled, the formation of this supply chain may dissolve or evolve into a
7 new structure for future demands. This 'trust by design' has led to the digital trust concept, as
8 proposed by Gartner (Gaehtgens and Allan, 2017), 'It is often said that trust takes years to build,
9 seconds to break and forever to repair. Digital trust, on the other hand, takes instants to build, an
10 instant to break and is continuously adaptive'.

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14 Digital trust may help prevent supply chain actors from behaving unethically or
15 opportunistically (Hill *et al.*, 2009; Wang *et al.*, 2014). Since every transaction in a blockchain builds
16 on every other transaction, any corruption or unethical behaviour will be readily visible to all network
17 participants. This is valuable to humanitarian supply chains where (inter)national aid is often
18 perceived as not reaching target beneficiaries (Hyndman and McConville, 2017). The built-in trust
19 would help brands build consumer-confidence when they know their products are from legitimate
20 suppliers. As Gupta (2017) pointed out, this self-policing mechanism can mitigate the need to depend
21 on current levels of legal or government safeguards and sanctions to monitor and control the flow of
22 business transactions.

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28 However, as there is no central authority to police or enforce honesty in a blockchain-enabled
29 supply chain, predicting future honest behaviour is impossible. Will collaborative relationship and
30 relational capital become less critical in a blockchain enabled supply chain? How will companies
31 build their reputation within a blockchain network? What happens if unethical behaviours take place?
32 How does distributed governance work in practice? To what extent will the blockchain reduce or
33 eliminate corruption in the supply chain, particularly in developing countries and humanitarian supply
34 chains where this problem prevails?

35 36 37 38 39 *5.4.4 Blockchain, inequality and supply chain sustainability.*

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41 When blockchain technology matures, some believe it could address social inequality and
42 poverty (Kshetri, 2017b; Tapscott and Tapscott, 2017). One scenario mentioned is international
43 remittance. This is the application area where a blockchain app is developed for people who work in a
44 developed country so that they can send money to their relatives who live in a developing country.
45 Traditional money transfers are processed through a network of central clearing bodies or
46 correspondent banks. There is limited visibility to value flow for both senders and recipients. The
47 whole process normally takes days and the transaction charges are high due to the number of
48 intermediaries involved. Also, those in receipt of monies frequently do not have a bank account.
49 Blockchain initiatives that target this problem could reduce the timing of international monetary
50 transactions of this nature to less than an hour (Abra.com, 2018).
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3 Similarly, the blockchain has been deployed in the food and beverage industry to tackle
4 poverty and ensure fairer and faster payments to small scale farmers. In the coffee sector, although 25
5 million smallholder farmers produce 80% of the world's coffee (Fairtrade.org, 2018), many fail to
6 earn a reliable living from coffee. Moyee Coffee (Case 16) launched a pilot project in Ethiopia with
7 the blockchain pioneers Bext360 and the FairChain Foundation to give all stakeholders—farmers,
8 roasters and consumers—access to data (including prices) across the entirety of the supply chain. Not
9 only did this bring radical change to traditional coffee supply chains, its potential social value could
10 be significant: offering opportunities for small businesses, addressing power imbalance between small
11 producers and large wholesalers/roasters, allowing a fairer distribution of value along the supply-chain,
12 and thus playing a significant role in poverty reduction.
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17 Another blockchain application that delivers social value is the Building Blocks pilot project
18 (Case 17) by the World Food Programme (WFP). The project uses an Ethereum-based blockchain
19 technology to help refugees of the Syrian Civil War. In the Azraq refugee camp in Jordan, 10,000
20 people receive food from entitlements recorded on a blockchain-based computing platform. Refugees
21 purchase food from local supermarkets in the camp by using an eye scan instead of cash, vouchers or
22 e-cards (WFP.org, 2017). This pilot has offered valuable insights for future humanitarian supply
23 chains and may enhance humanitarian agility and responsiveness—a key success factor in volatile
24 situations (Oloruntoba and Gray, 2006).
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29 The sustainability of blockchain deployment in the long-term remains uncertain. Its
30 predecessor M-PEASA resembles many of the desired social attributes pursued by blockchain
31 initiatives. The M-PEASA system was launched by Vodafone's Safaricom mobile operator in 2007 in
32 Kenya to allow those without a bank account to transfer funds quickly and easily. As of 2017, there
33 were 30 million users in 10 developing countries and services included international transfers, loans
34 and health provisions. M-PEASA was lauded for its social value impact, since 2% of Kenyan
35 households were lifted out of extreme poverty through access to mobile money services (Monks,
36 2017). As it took M-PEASA ten years to reach to a large-scale deployment in East Africa, we can
37 reasonably assume that the same level of impact by blockchain will not happen overnight. This
38 transition period will provide a fruitful time for theory-driven or theory-developing research to make
39 systematic inquiries as to how blockchains may transform the lives of individuals and the relationships
40 among individuals, organizations and society.
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47 Supply chain researchers have paid increasing attention to the social dimension of supply
48 chain management and its sustainability performance (Dillard *et al.*, 2008; Marshall *et al.*, 2015;
49 Pullman *et al.*, 2009). Often linked with the concept of corporate social responsibility (Eriksson and
50 Svensson, 2015) (Andersen and Skjoett-Larsen, 2009), the literature emphasises the impact of
51 business through engaging the poor as suppliers or customers (Márquez *et al.*, 2010). Research about
52 the bottom/base of pyramid (BoP) (Karnani, 2007; Khalid *et al.*, 2015) suggests that for technology to
53 serve its purpose of developing all stakeholders, including the BoP, the technology should be
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3 'participatory' (Berger and Nakata, 2013; Hall *et al.*, 2014). Blockchain-enabled social innovations
4 will provide interesting avenues for this stream of research.

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6 Future research should seek to explain how value is created, captured and distributed in
7 blockchain-enabled social supply chains. Efforts can also examine issues regarding conditions that
8 will ensure the survivability and prosperity of such initiatives. Theories and concepts from various
9 disciplines could be integrated to evaluate the effectiveness of these social innovations. Insights will
10 help broaden our understanding of the wider impact of blockchains on multiple supply chain actors,
11 including those who are vulnerable, exploited and poor.

12 13 14 15 5.4.5 *The dark side of blockchain.*

16 We adopt the broad term, 'dark side' (Tarafdar *et al.*, 2015), to depict potential negative
17 phenomena associated with blockchain use, with the potential to infringe on the well-being of
18 individuals, organisations and societies. Dark side phenomena include issues like governance, ethics,
19 law, crime, security, privacy, intellectual piracy, automation-induced unemployment and technical
20 vulnerability issues.

21
22 The dark side of blockchain technology is already evident in cryptocurrency. Several cyber
23 hacks have targeted popular cryptocurrencies. The criminal use of cryptocurrency is equally alarming
24 when the automatic and autonomous properties of a blockchain are exploited: money laundering,
25 illicit marketplaces and ransomware. Increasing cybercrimes lead to data breaches, financial crimes,
26 market manipulation, IP theft and public safety and security risks. This makes cybersecurity a top
27 priority for blockchain-enabled supply chains. The biggest challenge is that, unlike the Internet,
28 blockchains have no sophisticated governance system in place.

29
30 Technical vulnerability seems a far reaching issue for supply chain researchers, since we may
31 not be able to propose technical countermeasures. However, understanding how these vulnerabilities
32 are open to misuse and their subsequent impact on supply chain management is of paramount
33 importance. For instance, Juels *et al.*, (2016) pointed out a number of ways in which things could go
34 wrong in smart contracts. To build a secure blockchain supply chain, technology solutions are only
35 part of the integrative measures, as appropriate (inter)organisational policies and procedures, laws and
36 industry standards are needed. Supply chain researchers could play a part in the latter.

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38 Blockchain development presents significant regulatory challenges. The absence of an
39 intermediary in most or all steps of the supply chain could create uncertainty for the parties involved,
40 especially regarding automated forms of execution and transaction supervision of transactions.
41 Criteria are needed to ensure the legal validity and enforceability of smart contracts under the law
42 (Boucher *et al.*, 2017). Privacy is another challenge. As data is visible to all who participate in a
43 blockchain (whether public or permissioned), this level of openness may not be welcomed by all
44 supply chain actors, particularly end consumers.

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3 Through their distributed consensual nature, blockchains also threaten the role of
4 intermediaries. If those intermediaries could be eliminated, this would reshuffle the whole freight
5 sector and create fundamental changes. It may also result in job losses in the short-term, although new
6 intermediaries offering blockchain related digital services might emerge, creating new employment
7 opportunities. However, this means job reskilling is of critical importance for supply chains.
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10 Whilst the dark side use of technology has been actively discussed in the IT/IS discipline, this
11 issue has not received equal attention from supply chain researchers, although IT/IS has been
12 recognised as a key enabler to effective supply chain management. Tarafdar *et al.*, (2015) proposed a
13 guiding framework as a basis for research on dark side phenomena. They suggested that research
14 should look at the context of their occurrence, negative outcomes and mitigation mechanisms. They
15 further proposed that these aspects can be investigated at different level of analysis: individual,
16 organisational, and societal. Taking multiple theoretical lenses to examine these phenomena would
17 benefit the overall understanding of the relationship between blockchains and their potential negative
18 outcomes on a range of supply chain actors.
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24 5.4.6 *A design perspective on a blockchain-enabled supply chain*

25 This study has explored the aforementioned strategic issues that we think are worthy of
26 further investigation. Future work should also seek to develop valid knowledge that can directly
27 inform and support practice. Interest in design thinking and design science has increased in both the
28 operations management (van Aken *et al.*, 2016) and information technology/information systems
29 (IT/IS) disciplines (Baskerville *et al.*, 2018). In practice, large IT companies, such as SAP and IBM,
30 have been actively using design thinking methods to articulate problems or opportunities with their
31 clients and multiple stakeholders and to identify solutions that will deliver value to their target
32 beneficiaries.
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37 Whilst the design of blockchain-enabled supply chains is highly context dependent and no one
38 optimal design exists for all supply chains, researchers could aim to deploy a design science approach
39 that focuses on developing generic actions, processes and systems to address field problems or to
40 exploit promising opportunities afforded by the emerging technology of blockchain. The generic
41 design can then be operationalised in various contexts.
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45 From our review of practices, current efforts have been rather exploitative instead of
46 explorative and consist largely of a collection of incremental advances. Over time and as both
47 societies and industries grow in their use of blockchain networks; we anticipate structural changes to
48 business models across industries, which may then lead to significant socio-technological and
49 economic changes worldwide. One way of generalising knowledge from emerging practices is to
50 examine a number of case-specific designs of the intended domain and derive generic and transferable
51 essentials (mechanisms) which produce desirable outcomes (van Aken *et al.*, 2016). We offer a few
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preliminary observations from our understanding of the literature to inspire further research, and these are as follows:

- Selecting a blockchain's entry point to the supply chain

The starting point in designing a blockchain-enabled supply chain would be to identify areas where there are pertinent problems in an existing supply chain that blockchain technology would help address. This aspect is where a design thinking exercise could be introduced to elucidate and articulate areas where the blockchain may bring ultimate value to the supply chain. Typically, a problem or several problematic areas can be identified via brainstorming sessions with multiple stakeholders. Potential ideas/goals, as well as barriers/problems, will be explored. A clustering exercise could be conducted to group related issues into themes which can then be prioritised based on factors, such as value for organisations, time and ease of implementation. Once a use case is finalised, a POC can then be established and tested to determine how effective the performance is.

As discussed in Section 4.2, the sample problem needs to be one that is experienced by multiple players in a supply chain network. The core value of a blockchain system is in its shared, append-only, distributed ledger across a network of organisations. If the problem is organisational rather than interorganisational, the blockchain may not be the right technological solution. Another prerequisite is to consider whether sharing data securely across a supply chain is needed whilst protecting privacy. A private blockchain network would support a shared repository and ensure that confidential or commercially sensitive information is only broadcasted to relevant parties.

For the blockchain to provide value to supply chains, assets need to be transferred between supply chain players. A major difference between a blockchain and a traditional distributed database is that the blockchain can be used to record transactions of assets between organisations. Assets could be physical products or electronic files/intangible items, such as a letter of credit. Supply chain organisations that need to track how often and through how many parties an asset changes hands can benefit from the blockchain's provenance capability. The blockchain can also be deployed when greater trust and transparency are needed in a supply chain network, for example, to comply with legal regulations, reduce risks or avoid fraud.

- Building a blockchain ecosystem

Once a business case is identified, the next question to consider is who should participate in the blockchain-enabled supply chain. At the pilot stage, a small group of consortia with three to five participants has been suggested as a viable number needed to understand the core concerns and test assumptions across the solution space (IBM, 2016). This founding network can then expand to include more actors at a later stage. This consortium would usually include a lead organisation as a supply chain orchestrator (for instance, in case 1, it is Walmart, and for case 5, it is Maersk) that will play a significant role in shaping the direction of blockchain development and deployment and in coordinating the tasks of participating organisations to ensure that objectives are aligned and collective actions are agreed upon. Depending on the specific case involved, other participating

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3 organisations could include a technology service provider, a supplier and public authorities, such as
4 customs, banks or logistics service providers. The common incentives that encourage participation in
5 a pilot could be both tangible (e.g. cost and time reduction, new revenue or risk reduction) and
6 intangible benefits (e.g. industry leadership, standards development or first-mover advantages).
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- 8 • Articulating the platform value

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10 A blockchain-enabled supply chain can be viewed as a value platform, a concept proposed by
11 Perks *et al.* (2017), upon which network members co-create value through a set of specific practices
12 via the dynamic configuration of tangible and intangible resources. At the strategic level, its key
13 ingredients include value proposition, value creation and value distribution within the blockchain
14 network.
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16
17 The value proposition dictates the network revenue/cost model and its core
18 activities/processes. The consortium needs to decide, for instance, whether a membership fee should
19 be charged, how participants should pay and how transactions will be charged. Considerations should
20 also be sought about whether smart contracts should be coded into the blockchain and whether a
21 digital token should be utilised to facilitate transactions. The perception of a fair value distribution by
22 all participating members is critically important to maintain and nurture the resilience of the
23 blockchain value platform.
24

- 25 • Establishing the governance model

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27 Blockchain-enabled supply chain governance can be particularly challenging because of its
28 decentralised nature—each participant will have a stake in how the blockchain supply chain is
29 configured and operated. A set of rules on how the participating members interact with one another
30 needs to be determined. In terms of participants, one needs to clearly define a) the ways by which the
31 participants access or exit a blockchain network, b) the types of roles each member will play and c)
32 the ways to resolve potential disputes among members. In terms of data, considerations should be
33 given to concerns, such as the kinds of data that should be appended in the blockchain and the people
34 responsible for inputting the needed data. Once the data are in the blockchain, who has ownership of
35 them and how IP ownership should be dealt with need to be set, as well.
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38 In terms of transactions, those in charge of validating them and the number of nodes needed
39 should be established. In the case of a smart contract, clear roles and responsibilities on which party
40 should review and approve it and how the code captures the right business logic should be laid out. As
41 smart contracts have significant legal consequences, they further complicate the governance of the
42 blockchain network.
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45 The governance of a supply chain network has been well examined in the literature, and a
46 number of frameworks have been proposed (Milward, *et al.*, 2013; Provan and Sydow, 2007).
47 However, as discussed above, a blockchain-enabled supply chain makes determining the nuances of
48 governance mechanisms more complicated.
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- 50 • Exploring legal implications

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3 A number of unique legal matters emerge from a blockchain's distributed nature, as
4 blockchains are decentralised and, in many cases, global. They cannot be shut down by any one legal
5 system, and they exist outside the boundaries of conventional laws defined by jurisdiction. Local and
6 international laws, industry-specific regulations, data sharing regulations, intellectual property,
7 liability and general commercial agreements, such as the service level and performance assurances,
8 should all be carefully examined (IBM, 2018). Organisations should work with law professionals to
9 define rules and a detailed set of contingencies for anticipating potential legal issues.

- 10 • Scaling up a blockchain-enabled supply chain network

11 The IT/IS discipline has long explored the factors that influence the diffusion of
12 interorganisational technological innovations (Robey *et al.*, 2008). How these factors can be applied to
13 the emergence of blockchain technology has yet to be examined. In practice, the pioneers of
14 blockchain technology (as shown in Table 2) have asserted that if the future vision of a blockchain
15 network emphasises the sharing of value among all participants, it will likely attract more participants.
16 Other factors, such as interoperability with core enterprise IT systems, ease of use (e.g. multiple ways
17 of accessing the platform) and security of the system, will also help encourage further network
18 adoption.

29 6 Conclusion

30 This study explored how blockchain technology can potentially influence future supply chain
31 practices and policies. Basing on a systematic review of both the academic and practitioner supply
32 chain literature, we identified the main drivers of blockchain deployment within supply chains, as well
33 as within areas in which this emerging technology may provide the most value for supply chain
34 management. We have engaged with certain blockchain initiatives evident in contemporary practice to
35 demonstrate not only some of the technology's latest applications but also a range of technological,
36 organisational and operational challenges that are likely to affect its further diffusion.

37 The supply chain literature is particularly interested in blockchain technology as a way of
38 allowing organisations and individuals to make and verify transactions without needing a controlling
39 central authority. This feature is of great interest because it may facilitate digitalisation and
40 disintermediation in the supply chain, as well as resolve issues associated with inter-organisational
41 trust. However, the use of blockchain technology as a means of implementing distributed ledgers and
42 smart contracts raises as many issues as it resolves. From our analysis of the literature, we have raised
43 a number of issues associated with the potential socio-economic impact of blockchains and proposed a
44 range of future research avenues worth investigating.

45 To our knowledge, this study is the first to examine the current state of blockchain diffusion
46 within supply chains. Our work is timely in that it provides a solid foundation for evaluating a
47 technology whose benefits are not yet entirely clear, whose negative effects are unforeseeable and
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3 whose diffusion path remains uncertain. Our contribution has been to identify and organise the
4 otherwise disjointed studies published on blockchains in such a way that their relevance to the supply
5 chain management discipline becomes apparent. Academic scholars will hopefully gain some leverage
6 from this analysis, as it provides an understanding of the trends in the emerging landscape of
7 blockchain technology. Scholars new to it will find in this study both a comprehensive review of
8 blockchain fundamentals and a systematic analysis of blockchain research relevant to supply chain
9 management.

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13 From a managerial standpoint, the findings of this study can assist practitioners in making a
14 strategic sense of the disruptive effect and potential opportunities afforded by blockchain technology
15 to supply chains. This study not only pinpoints areas where blockchain technology may disrupt
16 existing supply chain provisions but also highlights certain challenges and barriers to the technology's
17 deployment. As such, our study should help guide managers' decisions about formulating and
18 implementing blockchain-enabled supply chain initiatives. From a design perspective, this study
19 offers both practitioners and scholars valuable insights into identifying a use case that addresses a
20 supply chain problem, operationalising the desired blockchain supply chain model and focusing on
21 legal and governance issues for long-term sustainability. Our findings serve to alert managers,
22 particularly the network orchestrator, of the need to nurture network relationships among participating
23 members and to develop a shared value among all members.

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29 Finally, although much care was taken in the selection of the search terms used in our study,
30 we acknowledge that our choice may have excluded certain blockchain articles from this review. As
31 blockchain development is still in its embryotic phase, our discussions of future research opportunities
32 are mainly conceptual. Whilst conceptualisation is an important process in making sense of related
33 blockchain observations, future research should keep a close track of blockchain developments and
34 add more empirical evidence to the various strands of research opportunities we have identified.
35 Revisiting this area and conducting another round of literature review once blockchain technology has
36 had time to mature as a supply chain technology would be worthwhile.

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Understanding Blockchain Technology for Future Supply Chains:
A Systematic Literature Review and Research Agenda

Tables and Figures

Figures

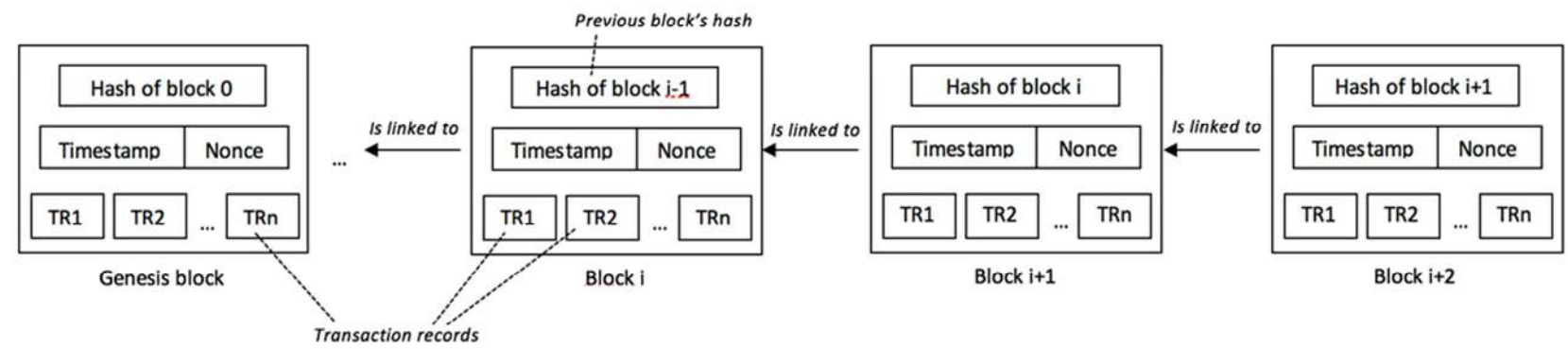


Figure 1: A standard blockchain string (Yli-Huumo *et al.*, 2016)

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Tables

Table 1: List of articles identified through systematic literature review

Research types	Paper	Focus	Applied areas	Key findings
Descriptive Papers (3 papers)	Bocek <i>et al.</i> , 2017	Traceability and integration of IoTs of blockchain	Pharmaceutical industry	Blockchain allows pharmaceutical supply chains to monitor temperature and humidity over the transport of medical products.
	Mackey and Nayyar, 2017	Anti-fraud	Pharmaceutical industry	A few blockchain use cases and initiatives were identified and briefly discussed for security and anticounterfeiting purposes.
	Lu and Xu, 2017	Product traceability	Agri-food industry	Using the originChain case demonstrates the value of blockchain in tracing the origin of products across complex supply chains. This blockchain system requires a transparent, tamper-proof metadata infrastructure that is also adaptable to changing environments and regulations.
Conceptual Papers (4 papers)	Hull <i>et al.</i> , 2017	Challenges of smart contract implementation in supply chains	Global supply chains	Single trusted source of data from blockchain will contribute to streamlined data sharing and dispute resolution. Smart contracts will prevail in supporting supply chain collaboration but several challenges need to be addressed: diversity and variation in country policies, product types, transport and tax rates; programming language, solution architectures, interoperability and verification process.
	Mansfield, 2017	Blockchain concept and its future implications	Pharmaceutical, gemstones, airline industries	Blockchain's impact will reach far beyond financial sectors providing 'assurance as a service' in the commercial world.
	Patel <i>et al.</i> , 2017	Blockchain concept, technical fundamentals, application cases of blockchain	Multiple sectors	Blockchain technology will revolutionise several financial and non-financial sectors. However, it will also face security, legal, regulatory and technological challenges.
	Shireesh Apte and	Value and limitation of blockchain	Pharmaceutical industry	Blockchain will enable advances in authentication and validation of supply chain information

	Petrovsky, 2016	in verifying material ingredients		auditing process.
Predictive Papers (11 papers)	Casey and Wong, 2017	Product traceability	Global supply chains	End-to-end traceability and the encrypted inclusion of human beings to the supply chain audit is a significant value of blockchain.
	Collomb and Sok, 2016	Disintermediation effect of blockchain	Global supply chain	Disintermediation in international trade finance and settlement will increase efficiency in cross-border operations.
	Glover and Hermans, 2017	Product traceability	Pharmaceutical industry	Blockchain technology has the potential to improve the traceability of a clinical trial supply chain and track patient responses.
	Guo and Liang, 2016	Disintermediation effect of blockchain	Global supply chains	Disintermediation and digitization of supply chain finance enabled by blockchain will enhance the efficiency in cross border trade settlement.
	Korpela <i>et al.</i> , 2017	Digital supply chain integration	Manufacturing/physical distribution	Blockchain will enable hyper-levels of supply chain integration with end-to-end integration of product and process data.
	Kshetri, 2017a	Integration of blockchain with IoTs	Manufacturing/physical distribution	Blockchain can play a key role in tracking the sources of insecurity in supply chains and in handling crisis situations like product recalls that occur after safety and security vulnerabilities are found.
	Kshetri, 2017b	Potential value of blockchain to reduce corruption and fraud	Global supply chains (in relation to the third world economy)	Blockchain will enable the promotion of transparency in international trade finance in the third world.
	Lee and Pilkington, 2017	Transparency and supply chain visibility	Electronics industry	Transparency and process integration in consumer electronics supply chain management will be enhanced by blockchain. Areas where blockchains can affect supply chains include a tamper-proof history of product manufacturing, handling and maintenance, digital identity for ownership and packaging, tendering across the supply chain through smart contracts and engagement with consumers.
	Shanley, 2017	Supply chain security, traceability and technical obstacles	Pharmaceutical industry	Blockchain's serializations of products and tracking of origin will be significant value of pharmaceutical supply chains.
	Wang <i>et al.</i> , 2017	Transparency and traceability, contract and asset management	Construction industry	Three types of blockchain-enabled applications are proposed to improve the current processes of contract management (notarization), supply chain management (transparency and traceability), and

		and challenges of implementation		equipment leasing (asset management) for construction engineering management.
	Saberi <i>et al.</i> , 2018	Information authenticity and product stewardship	Reverse logistics and product recycling	Blockchain-enabled product life cycle assessment and end-of-life management will benefit reverse logistics industry.
Prescriptive Papers (11 papers)	Engelenburg <i>et al.</i> , 2017	Smart contract	Global supply chains	Followed a design science approach to develop a software architecture for business-to-government information sharing for cross border activities enabled by blockchain technology.
	Chen <i>et al.</i> , 2017	Smart contract and smart inspection	Personal computer industry	A blockchain-based supply chain quality management (SCQM) framework is proposed which consists of IoT sensor, blockchain data, contract and business layers.
	Li <i>et al.</i> , 2017	Supply chain visibility and real-time tracking	Manufacturing/physical distribution	A framework that supports supply chain visibility by using a hybrid (semi-open) P2P architecture is introduced, providing the cost-effective real-time tracking information of shipments to all stakeholders.
	Nakasumi, 2017	Information symmetry and capacity risk mitigation	Global supply chains	A blockchain-based solution is proposed to address the problems of double marginalization and information asymmetry in supply chain.
	Polim <i>et al.</i> , 2017	Information integration capability of blockchain	Advanced transport systems development	A blockchain data structure is designed to promote fair competition among 3PLs in a retailer-centred network and the system removes the intermediary 4PL.
	Tian, 2016	Product traceability	Agri-food industry	A conceptual framework for an agri-food supply chain traceability system is proposed, integrating RFID and blockchain technology.
	Tian, 2017	Product traceability	Agri-food industry	To address the scale-up issue of blockchain application, a decentralized traceability conceptual system based on IOTs and blockchain technology was proposed. A scenario demonstrated how it works in a food supply chain with Hazard Analysis and Critical Control Points (HACCP).
	Toyoda <i>et al.</i> , 2017	Anti-fraud and product authenticity	High value product supply chains	A blockchain-based product ownership management system is proposed for anti-counterfeit in the post supply chain. A proof-of-concept experimental system has been implemented on the Ethereum platform and results demonstrate the cost for managing products with the proposed system is less than US\$1 when the number of owner transfers is less than or equal to six.
	Weber <i>et al.</i> , 2016	Inter-organisational business process monitoring and execution (smart contract)	Manufacturing/physical distribution	Specific techniques are proposed to integrate blockchain into the choreography of processes in such a way that no central authority is needed, but trust maintained in a collaborative process execution.

	Xu <i>et al.</i> , 2017	Secure information integration and sharing	Manufacturing and physical distribution	A supply chain on blockchain management system is proposed that uses a hybrid model and two-steps method to maintain a decentralized ledger based on blockchain. It introduces a protection mechanism to prevent supply information stored on the ledger from being accessed by unauthorized participants.
	Yuan <i>et al.</i> , 2016	intelligent transportation systems (ITS) and real-time ride-sharing	Advanced transport systems development	A blockchain-based ITS (B ² ITS) conceptual framework is proposed, highlighting its potential in supporting sharing economy in transport.

Table 2: A list of popular blockchain initiatives in practice

Case number	Industrial focus	Led by	Case description (source of information)	Supply chain objectives	Blockchain platforms	Source	
1.	Product provenance and traceability	Walmart and other large food businesses	Since October 2016, Walmart has been working with IBM in a pilot study to trace food products in the blockchain. In April 2018, Walmart started to get suppliers involved in the blockchain. Following this, Dole, Driscoll's, Golden State Foods, Kroger, McCormick and Company, McLane Company, Nestlé, Tyson Foods, Unilever, Walmart and others started to collaborate with IBM in order to further champion the blockchain.	To improve food safety, achieve product provenance and reduce fraud	Hyperledger Fabric	Russo (2018) and IBM (2017c)	
2.		Provenance	Provenance, a UK social enterprise organisation, is one of the early pioneers providing blockchain-enabled solutions for product tracking and tracing. This tech start-up has successfully piloted two projects: a) tracking tuna through southeast Asian supply chains in 2016 and b) working with a large consumer cooperative to track fresh produce from its origin to the supermarket in 2017.	To increase the integrity of certifications, as well as ensure food provenance and fair payment	Ethereum	Provenance (2017)	
3.		Everledger	In 2015, London-based start-up Everledger first started to securely track and trace the authenticated provenance of diamonds by using the best of emerging technology on a global digital ledger. Working with a range of stakeholders across the diamond supply chain, Everledger has since encrypted the provenance of over 2 million diamonds in a short span of three years.	To create and track the entire lifetime journey of a diamond in a manner that is accessible to all	Hyperledger Fabric	Everledger (2018)	
4.		Airbus and others	Airbus, the French aircraft maker, is looking to use blockchains to monitor the many complex parts that come together to make a jet plane. A number of airlines have already expressed a keen interest in developing blockchain solutions, with the likes of Lufthansa, Air New Zealand and British Airways already working with blockchain start-ups on ambitious projects. (https://cryptonews.com/news/airbus-rolls-royce-seeking-blockchain-air-parts-traceability-1700.htm)	To create and maintain trust in supply chains and to automate records for complex products that currently require significant manual efforts	Hyperledger Fabric	Alper (2018)	
5.		International shipping, cross-border supply chain	Maersk	Working with IBM, Maersk did a POC in September 2016, tracking a container of flowers from Kenya to Rotterdam. Following this, a few pilots, including the international shipment of electronics from Rotterdam to Newark, as well as that of Mandarin oranges from California and pineapples from Colombia to Rotterdam, were completed in 2017.	To digitalise global trade (paperless trade) and provide end-to-end supply chain visibility	Hyperledger Fabric	Groenfeldt (2017)
6.		Hyundai Merchant Marine (HMM) (South Korea)	HMM announced in September 2017 that it successfully completed its first blockchain integrated pilot voyage from South Korea's Busan port to China's Qingdao port with reefer containers from August 24 to September 4, 2017. Blockchain was applied not only to shipment booking but also to cargo delivery. HMM also tested and reviewed the combination of DLT with IoT through real-time reefer-container monitoring and management on the vessel.	To allow secure information sharing between multiple stakeholders, reduce paper work and ensure	Ethereum	HMM (2017)	

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5	7.	Pacific International Lines (PIL) and the Port Authority of Singapore (PSA) (Singapore)	Following the signing of the MOU in August 2017, PIL, PSA and IBM worked on a POC exercise to track and trace cargo movement from Chongqing to Singapore via the Southern Transport Corridor. The pilot was considered successful in December 2017. The partners believed that sufficient evidence now exists to show that the concept can be taken to the next stage.	To enhance the security, transparency and efficiency of the supply chain network in southeast Asia	Hyperledger Fabric	PIL (2018)	
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15	8.	Daimler and Landesbank Baden-Württemberg (LBBW)	Daimler AG and LBBW jointly used blockchain technology to execute a financial transaction. Through LBBW, Daimler launched a €100 million one-year corporate Schuldschein, in which savings banks (Kreissparkasse) Esslingen-Nürtingen, Ludwigsburg and Ostalb, as well as LBBW, acted as lenders. The entire transaction was digitally carried out via blockchain technology, in cooperation with the IT subsidiaries TSS (Daimler) and Targens (LBBW).	To make financial processes simpler and more efficient and to enable new business models	Hyperledger Fabric	Daimler (2017)	
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21	9.	Foxconn and Dianrong	The financial services arm of iPhone manufacturer Foxconn (Taiwan) partnered with the Chinese online P2P lender Dianrong to launch Chained Finance, which claims to be the first-ever blockchain platform for supply chain finance. The two companies recently completed a successful pilot and POC by securing funding for small and medium enterprises (SMEs) in China that were otherwise unable to secure their needed capital. (http://www.scmp.com/tech/leaders-founders/article/2102840/blockchain-sharpens-dianrongs-edge-p2p-lending-small)	To provide supply chains with easier access to funding at competitive rates	unknown	Soo (2017)	
22		Trade finance					
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28	10.	Skuchain	CGI, a trade finance platform used by banks in 90+ countries worldwide, and its banking partners successfully completed a POC in 2017, which integrates CGI's trade finance platform (CGI Trade360) and its blockchain-based platform (Skuchain Brackets) to demonstrate how banks can provide trade finance services digitally to their customers conducting business on blockchain B2B platforms.	To establish seamless interoperability between a trade platform and a supply chain execution platform	Hyperledger	Market Insider (2017)	
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34	11.	OriginalTrail	OriginalTrail is a Slovenian IT company specialising in traceability and quality control systems, and it created the cryptocurrency Trace Token. The purpose of this currency is to serve as compensation for the multiple nodes within a network that keep copies of transactional data generated by supply chains. This may address the issue of high transaction costs associated with the blockchain and would speed up cash flow exchanges.	To assist in the financial settlement between supply chain partners	Ethereum	OriginTrail (2018)	
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40	12.	Data security and dispute	NHS	Google's DeepMind is working with Britain's National Health Service (NHS) to deploy a private blockchain for creating robust audit trails that track exactly what happens to personal data.	To ensure the security of patient data	Unknown	Suleyman and Laurie (2017)
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13.	resolution	FedEx	FedEx, a multi-national shipping company, launched a pilot program using blockchain to store data for dispute resolution. The company comes into the blockchain sphere in the wake of a high-profile cyber-attack on its TNT express branch in Europe last year.	To streamline all data exchanges in a secure way	Ethereum and Hyperledger	Rajamanickam (2018)
14.	Smart contract	Slock.it	Slock.it, a German start-up, has partnered with energy giant RWE to transform the way electric cars are charged. Cars with digital wallets will be able to 'talk' to autonomous electric charging stations which use smart contracts in order to allow users to rent the station, put up a deposit, charge their car and then get their deposit back.	To speed up, simplify and automate the electric car charging process and payment settlement	Ethereum	Allison (2016)
15.		Barclays	Barclays Corporate Bank recently partnered with a start-up, Wave, a platform that stores bill-of-lading documents in the blockchain and uses smart contracts to log change of ownership and automatically transfer payments to ports upon arrival.	To streamline cross-border trade finance	Waves	Ream et al (2016)
16.	Social impact	Moyee Coffee	Moyee Coffee (www.moyeecoffee.ie) launched a pilot project in Ethiopia in November 2017 with blockchain pioneers Bext360 and the FairChain Foundation to give all stakeholders access to data across the entirety of the supply chain. At the point of collection, the Bext360 platform instantly creates cryptotokens. As the commodity flows through the entire supply chain, new tokens are automatically created. These tokens increase in value as the beans move through the supply chain.	To create a fairer and honest supply chain	Stellar (a payment network)	Moyee Coffee (2018)
17.		WFP	The Building Blocks pilot project by the World Food Programme (WFP) initiated a POC in 2017 using an Ethereum-based blockchain technology to help refugees of the Syrian Civil War in the Azraq refugee camp in Jordan. As of January 2018, more than 100,000 people have received food from entitlements recorded on a blockchain-based computing platform. Refugees purchase food from local supermarkets in the camp by using an eye scan instead of cash, vouchers or e-cards.	To reduce payment costs associated with cash transfers, better protect beneficiary data, control financial risks, and set up assistance operations more rapidly in the wake of emergencies	Ethereum	WFP (2017)

Table 3 Drivers of blockchain deployment (Source: authors)

Drivers	Reference
Trust: reliability and security of information	Collomb and Sok, 2016; Hull <i>et al.</i> , 2017; Michelman, 2017; Nakasumi, 2017; Patel <i>et al.</i> , 2017
Supply chain disconnections and complexities	Li <i>et al.</i> , 2017; Nakasumi, 2017; Bonino and Vergori, 2017; Wang <i>et al.</i> , 2017
Product safety, authenticity and legitimacy	Tian, 2016; Tian, 2017; Toyoda <i>et al.</i> , 2017; Mackey and Nayyar, 2017
Public safety and anti-corruption	Engelenburg <i>et al.</i> , 2017; Kshetri, 2017b; Guo and Liang, 2016

Table 4: Paradigm shift of international trade by blockchain technology (Source: Collomb and Sok, 2016)

Business paradigm	Current international trade and supply chain	Blockchain based international trade and supply chain
System architecture	Trusted third-party/ central coordinator based platform	Decentralized / peer-to-peer transaction based network
Database	Single copy in data repository	Peer verified multiple copies
Security	Controlled access/ firewalls	Cryptography
Transaction execution	Intermediation	Smart contract based on consensus/proof of work